The Interdependence of Abstract Science and Engineering—

By William Anderson—

THE

INTERDEPENDENCE OF ABSTRACT SCIENCE AND ENGINEERING.

BY

Sir WILLIAM ANDERSON, D.C.L., F.R.S., M. Inst. C.E.

BEING

THE "JAMES FORREST" LECTURE

DELIVERED AT

The Institution of Civil Engineers.

SESSION 1892–93.

By permission of the Council.
Excerpt Minutes of Proceedings of The Institution of Civil Engineers.
Vol. cxiv. Session 1892–3. Part iv.

LONDON:
Published by the Institution,
25, GREAT GEORGE STREET, WESTMINSTER, S.W.
[Telegrams, "Institution, London." Telephone, "3051."]
1893.

ADVERTISEMENT.

The Institution as a body is not responsible either for the statements made, or for the opinions expressed, in the following pages.

LONDON: PRINTED BY WM. CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

THE INSTITUTION OF CIVIL ENGINEERS.

EXTRA MEETING.

4 May, 1893.

HARRISON HAYTER, President,
in the Chair.

THE "JAMES FORREST" LECTURE.

Mr. Harrison Hayter, President, said the members were assembled on that occasion pursuant to the following notice, dated April 29th:—

"The Council beg leave to intimate that there will be an Extra Meeting on Thursday, May 4th, at 8 P.M., when Dr. W. Anderson, F.R.S., M. Inst. C.E., will deliver the first 'James Forrest' Lecture, his subject being 'The Interdependence of Abstract Science and Engineering.'"

The date chosen for these lectures was the anniversary of the election of the Secretary, Mr. Forrest, as an Associate of the Institution, which event took place on the 4th of May, 1852. They all regretted very much that Mr. Forrest was prevented by illness from being present on this occasion, but he had written a letter, which, he thought, the members would like to hear—

Hastings, *May 1st*, 1893.

My Dear Sir,—I deeply regret to have to report that my medical adviser will not sanction my return to London in time to be present at the lecture on Thursday evening. He considers that I am in too debilitated a condition to bear the strain of such an ordeal.

Under these circumstances I must ask you to express to the Council and members how highly the great compliment is appreciated, by which it is intended to identify my name, for all time, with the work of the Institution which I have, for many years, endeavoured faithfully and honestly to serve to the best of my ability.—With every respect, I remain, my dear Sir, yours very faithfully,

(Signed) James Forrest, *Secretary.*

Harrison Hayter, Esq., *President of The Inst. C.E.*

It was quite unnecessary to introduce Dr. Anderson to the meeting, and he would therefore, without further preface, call upon him to deliver the lecture.

"The Interdependence of Abstract Science and Engineering."

By WILLIAM ANDERSON, D.C.L., F.R.S., M. Inst. C.E.

Before commencing the task which has been imposed upon me by the Council, I think it will be well to explain the origin of the "James Forrest Lectureship."

During the Session of 1889–90 the Council of the Institution determined to have a portrait of Mr. Forrest painted with the view of presenting it to the Institution. An admirable likeness was produced by Mr. Wm. M. Palin, and it was presented at the Ordinary Meeting of November 11, 1890. As soon as the members had seen the portrait a large number expressed a wish to have an engraving of it; a Committee was formed outside the Council, funds were rapidly collected, and an excellent engraving, by Mr. Thomas Faed, R.A., was produced and distributed, while the surplus fund, amounting to about £500, was placed at the disposal of the Secretary, who determined that it should be devoted to the establishment of a "James Forrest" Lectureship, and that it should be administered by the governing body of the Institution for the time being, who would select the lecturer and determine the subject of his discourse.

This is the first lecture under the trust. The high and undeserved honour of delivering it was imposed on me; I accepted the task with much hesitation and misgiving, being deeply conscious that I was incompetent to do justice to the occasion.

The theme which has been prescribed is "The Interdependence of Abstract Science and Engineering," and I imagine that the subject has been chosen because of an uneasy feeling, which possesses many thoughtful men, that this country is not keeping pace with its neighbours in engineering progress, and that we shall, in the future, have to pay more attention to abstract science and its application to practice, than we have been, so far, in the habit of doing, if we are to come out victorious from the competition, ever increasing in keenness, which we meet with from abroad, and which our system of unrestricted trade tends so much to foster. It is impossible to visit the Continent of Europe, the United States of America or even our

own Colonies, without feeling conscious that, in many respects, their engineering works and their factories, to say nothing of their military and naval arsenals, exhibit the great advantages which have accrued from the employment of men of the highest scientific culture in the conduct of those enterprises—that the days are past when an engineer can acquit himself respectably by the aid of mother-wit alone, or of certain constructive instincts, which have been almost the only guides of engineers and manufacturers, even down to quite recent times.

This Institution has already shown, in the regulations not very long established with respect to the qualifications of the Student-class, that it is alive to the fact that some scientific training is desirable in a profession in which the lives of human beings, to say nothing of their property, are dependent on the knowledge and skill possessed; that in the vast works now undertaken a good deal more than intuition is necessary, and that scientific knowledge and training are attributes which the public have a right to demand of its engineers. So strongly does this feeling exist that it has assumed practical expression in the form of Science Colleges, which have been founded, either by individual liberality or by subscription, in every considerable town in the provinces, completely eclipsing London, where the movement first began, but where it languishes for want of adequate support, except, indeed, in the noble endowments of the City and Guilds schools, and the Government establishments at South Kensington.

The old arrangement must come to an end, we must not be deceived by our past experience when, supported by our immense and exceptional natural advantages, it may be admitted that our rough system worked fairly well.

In those days, and the practice survives even now, a public school-boy was taken into an engineer's office or into a factory, and there he exchanged his small store of dead languages for an equally slender equipment in science, acquired as it best could be, while following the routine of his master's practice, the said master being himself but scantily provided with anything more tangible than experience, an endowment which, from its very nature, is incapable of being communicated fully, and which can only be acquired by the professional activity of a lifetime.

It has often been my good fortune to discuss with Continental engineers the relative advantages of the English and foreign systems of training. The foreign engineer had, as a rule, an admiration for what he called our practical methods, and lamented

that, in his own country, training was almost exclusively theoretical; but I think that the superior education of the operatives abroad was not sufficiently recognized—the managers, the foremen, the draughtsmen, and even to a great extent the mechanics and other operatives, had had the advantage of technical training even before they began to acquire mechanical dexterity, so that the want of practical knowledge in the leaders has been met by a fair amount of theoretical knowledge engrafted on the practical experience of the followers, and it is incontestible that this combination is producing results as advantageous to our foreign competitors as it is disastrous to our own industries.

With rare exceptions, in this country, has there been even a slender amount of theoretical knowledge imparted to the various grades of employment; it is only during the last few years that Science Colleges and technical education in schools and People's Palaces, are beginning to bring our operatives up to the level of our foreign friends, but, unfortunately, too late to retain that pre-eminence which we at one time could claim, and, I fear, placed too much confidence in; and moreover, a new danger has arisen in the circumstance that popular scientific education has taken a one-sided direction, that of mechanical or technical knowledge alone, so that, though the operative approaches his work with increased intelligence, he remains unfit to reason out the great economic problems on which his own welfare and that of the nation depend.

It is a matter of extreme surprise to me that so little attention is paid to the science of Political Economy, that not only the mass of the people, in whose hands the voting power now lies, but even, in a great measure, the representatives whom they elect, have no systematic training in, and are grossly ignorant of, the principles which lie at the root of national prosperity. The further misfortune follows that politicians of the highest position do not scruple to trade on this ignorance, or to pursue a course which, in its consequences, is as bad—being ignorant themselves they strive to lead the ignorant, and set the operative against his employer and against society in general. The cheapness of newspapers, their wide diffusion, and their blind, not to say reckless advocacy of popular fallacies acting on the ignorance, prejudices, and discomfort, if not suffering, of the operative classes, are giving enormous power to trade organizations, whose avowed object it is to improve the earnings and social standing of the operative at the expense of, or at any rate without regard to, the interests of every other class in the community, and this is to be accomplished

not by encouraging education, not by advocating thrift and temperance, not by urging the workman to improve his mechanical dexterity, the thoroughness of his work and the amount which he produces, but by holding out visions of shortened hours of labour, by compelling a minimum of pay which will enable him to live in comfort, of systematically restricting the amount of work done by each individual, even in the shortened day, all under the fatal illusion that by such means a greater number of men will find more remunerative employment.

The employer is usually credited, by the trade leaders, with accumulating wealth without effort, risk, or anxiety, by the slavish labour of his operatives, while the proofs to the contrary, so easily to be obtained in the slender dividends declared by most industrial enterprises, and in the records of the Bankruptcy Courts, are steadily kept out of view.

There would be no fault to find with the new class of professional agitators, who live by the discontent which they foment, were they, and the Unions which they manipulate, to contribute in the smallest degree to the obtaining of that work and of those orders, in the execution of which the wage-earning portion of the community have their being. This, the most difficult part of every commercial enterprise is left to the much-abused capitalist, so that the absurd and impossible system is fast asserting itself, that professional skill, mercantile ability and capital shall obtain the work, and run all the risks of design, execution, and financial security; but that work shall be carried out according to rules which self-constituted and perfectly irresponsible bodies choose to impose. The smallest acquaintance with the principles of political economy would demonstrate that such methods must end in ruin, that they are utterly incompatible with our policy of Free Trade—a system which is perfectly reasonable and proper if thoroughly carried out, and which certainly never contemplated the protection of one particular class, and that, not by edict of the State, but at the bidding of self-constituted tribunals whose claims amount to this:—that there shall be free trade in all products which the operatives require to buy, but the strictest protection as to all that they have to sell, namely their labour, and whose ultimate methods are violence, and the coercion of all who differ from views which many intelligent but timid workmen know to be at variance with the true interests of their class.

Under all this lies the socialistic idea of equality in the condition of every member of the community, an idea which Political Economy demonstrates to be utterly Utopian and impossible.

Since the creation of mankind the differences in social position and in material comfort which follow naturally from the endless variations of mental and bodily powers in men, have existed, and, in spite of many abortive attempts, more or less violent, to establish equality, will exist for ever;—for it seems to me that the doctrine of Carnot with respect to heat-engines applies by analogy to the question of national prosperity. To obtain mechanical power from a source of heat there must be a fall of temperature, and the greater that fall is the more efficient will the engine be—a dead level of temperature simply means extinction of energy and of life. To ensure active trade and prosperous manufactures there must be a fall of money or of its equivalent from the wealthy to the comparatively poor, the one class is absolutely essential to the other; the prosperity of the community is bound up in the existence of these differences, and a dead level of wealth would be a dead level of poverty, which would end, as a state of uniform temperature must end, in absolute stagnation and death.

However much we may regret the inequality which exists in the distribution of wealth and comfort, it is just as much a law of nature as the unequal distribution of warmth, of sunshine, or of rain, and seems to me to follow naturally and inevitably from the endless variations in the physical, moral, and mental powers of human beings, and, therefore, to be as unalterable at the bidding of man as these attributes are. It only remains for us to recognize the fact, to make the best of it, and to avoid the gross wickedness of attempting to delude the poorer and more ignorant members of the community by incessant representations that it is the greed and selfishness of the wealthy which keep them low.

If the so-called "working man" be the embodiment of all that is needed for the industrial prosperity of a country, and if the possession of capital and the far wider consequence, the existence of credit, be a crime, why does he not arise in his strength and exhibit the faculties of combination which are so well illustrated in the trades unions, and establish engineering works, and manufactories, or undertake engineering enterprises from which he will be able himself to reap the golden harvest which the capitalist and the shareholder are supposed to gather, and who thereby excite his envy and arouse his hatred. The reason is very obvious.

Saturday night comes with unfailing regularity, and the week's wages must be met; work has to be found, usually at prices to be calculated beforehand, and when obtained, contracts do not always go on smoothly; engines and machines will not always

work; accidents will happen; long credits must be given; and those men who possess the talent and education to originate and the skill to administer, are comparatively very few, even in this land of enterprise, and have their value, which it is too much to expect that they will not take advantage of; while the buildings, machinery, stock and floating money, which form the capital—of the true nature of which such terrible ignorance exists—are absolutely valueless without the skill and the industry necessary to obtain remunerative employment; while the matter of credit, on which so large an amount of our activity depends, is almost a personal matter, and could never be commanded by a body of operatives, however respectable.

Co-operative enterprises are much talked of just now, and in some cases of shopkeeping have been successful, because such undertakings have been conducted on cash principles and under the ordinary conditions of trade. But co-operative manufacture, in which the workmen without capital are to share the profits are simply impossible, because they have no means of sharing the losses. It is singular how, in discussing enterprises to be conducted on the profit-sharing principle, the necessity of providing for loss-sharing is left out of consideration, though the grim reality asserts itself quickly enough when attempts are made to start manufactures, even on the smallest scale, without capital, for the unfortunate co-operatives soon discover that obtaining orders is a much more difficult business than executing them, and that capital is indispensable to command regularity in the conduct of work and in the payment of wages.

In deference, I presume, to the immense numerical importance of the operative classes, politicians are vieing with each other in supporting the impossible claims put forth—claims which, if conceded, will only precipitate the ruin of the class they profess to benefit, and which already, in the form of what may be termed benevolent legislation in favour of the operative, is heaping up elements of cost which our productive energy is unable to bear. The absurd cry that manual labour is the sole source of wealth has been well combated by that acute reasoner, Mr. Macfarlane Gray, who, in a recent discussion on the labour question, happily compared the body politic to a tree. The popular belief is that plants are nourished through their roots, which for that reason are believed to be the all important parts, while the leaves are mere ornaments, enjoying the upper air and sunshine and profiting by the work done underground. But a juster knowledge, one of the fruits of abstract investigation, tells

us that the roots are mainly useful in holding the tree erect, and have comparatively little to do with providing the materials for building up its structure. It is the leaves which form the great laboratory in which the main components of the plant are extracted from the region where superficial observers would least expect to find them—namely, from the atmosphere. He compares the roots to the operatives' part of the community; the trunk and leaves to the monetary, the scientific and the commercial part which drew from far and wide that which is necessary to keep the growth advancing and maintain it in health. The roots may just as well claim to be the sole sources of life in the tree as the operatives may claim to be the only producers of wealth, and conversely the leaves could, with as much reason, consider themselves as the only essential portion of the plant as the merchant or the capitalist claim to be independent of the operatives. Each grade in the body politic is essential to the other; it is an axiom that there can be no degrees of comparison between essential parts; and those who, from ignorance or from interested motives, persistently preach the doctrine of the superior importance of the "masses" over the "classes" are inflicting a deep injury on the prosperity of the country, and especially on those whom they so grossly flatter.

It seems to me that a very great national danger is being incurred by this systematic neglect of Political Economy—an abstract science which had its origin in this country, but where its teachings are ignored in a manner which must end in disaster, the signs of the advent of which are, I fear, only too plainly apparent.

Even in my lifetime a great change has come over the methods of executing engineering work. During my apprenticeship in Manchester I was associated with workmen—millwrights they were called—perfectly uneducated, but of the utmost intelligence—men whose workboxes contained the tools of nearly every trade and who could handle those tools with dexterity and skill. Before the days of easy communication they were sent away to great distances in charge of works, both extensive and intricate, and executed them, as a rule, with a thoroughness and an intelligence which left nothing to desire. The necessities of the present age have rendered great subdivision of work inevitable, and the action of trades' unions is restricting the range of the workman's acquirements, so that there are but few mechanics left who are conversant with many trades, or whose characters and experience enable them to be as self-contained and trustworthy as

the millwright of old; hence it seems to me hopeless to expect that, in the engineering trades, at any rate, the workmen will ever be able to dispense with the commercially-educated and experienced capitalist and the highly trained scientific staff he finds it necessary to employ.

And let it not be supposed that this, and kindred institutions, have no interest in the question. Our prosperity rests upon the well-being of our members, and that again depends upon the activity of trade and upon the existence of enterprise. But the "dividend grabbers," as investors in industrial enterprises are elegantly called by the foolish and ignorant men by whom the operatives are content to be led, will not embark their money in ventures where there is no prospect of reasonable interest, or where the hopes of such interest are endangered by labour agitations, encouraged, to a great and fatal extent, by political parties, who do not scruple to purchase votes by holding out all kinds of Utopian prospects.

But money must be invested; it cannot, in these days, be hoarded in strong boxes, as it was in Pepys's time; consequently our capitalists will search for outlets abroad, and by promoting industrial undertakings outside our shores, will, through the action of free trade, beat down the value of produce still more, and so further arrest the development of that manufacturing and engineering enterprise upon which our prosperity depends.

One method of combating this, I have pointed out, is the dissemination of sounder views on Political Economy concurrently with the spread of technical education. The other course is to pay more attention to abstract science and to devote more time to the study of what is going on around us in the world. I am afraid that the nature of the education of the wealthier classes in this country is responsible for a good deal of the insular conceit and exclusiveness with which, in spite of our peripatetic tendencies, we are still afflicted. Classical education, no doubt, has its merits, and is well suited to a large section of the community; but in these days of the extensive scientific knowledge which a competent engineer is bound to acquire, the universal application of the method seems to be a mistake, while I cannot but think that the acquisition of modern languages and scientific study are fully as efficient in training the minds of the young as they are incomparably more useful in the battle of life afterwards.

Nor am I singular in this view. Successive Presidents of this Institution, in their inaugural addresses, have dwelt upon the cardinal importance of the education question, and within the last

two or three years the Council has exacted conditions as to liberal education and scientific training from the candidates for student membership, which cannot be regarded as otherwise than happy; and without doubt, before very long, even in the higher grades of membership, evidence will be demanded of special attainments in abstract science which are now so accessible to all in every part of the Kingdom. I do not, for a moment, lose sight of the practical training, which I consider so essential to the qualifications of an accomplished engineer. I recognize the fact that there is a tendency in the pendulum of knowledge to swing to the opposite extreme, and of the rising generation of engineers to wax conceited, and to imagine that the diplomas obtained at Universities are guarantees of fitness to commence professional work at once. And here again I am in accord with many Past-Presidents, who, in their addresses, have dwelt on the importance of practical training. I hold that the engineer's education should begin earlier, even at school, and should embrace those branches of knowledge which, in our great public schools, are still, in a great measure, ignored, or taught in a half-hearted manner, more as a concession to the utilitarian spirit of the age than as an essential equipment for many professions.

But nothing, save bitter experience, will alter the course of events. It seems to be the fate of peoples to attack social problems from the wrong end, to solve them by the painful and dilatory process of trial and error, rather than by means of investigation based on first principles. And this method is commonly applied to engineering problems also. Random trials, as a rule, are the methods by which great results have been achieved, while the application of the scientific principles involved have been left to other heads long after the results sought have been attained at much needless cost, and by much unnecessary expenditure of labour and of time.

It is not often that a genius of the order of James Watt rises in the mechanical world. Up to the time when the University of Glasgow required its model of a Newcomen engine to be repaired, the "fire-engine," as it was most properly called, was being slowly developed without any exact knowledge of the properties of the agent by means of which the heat generated by the combustion of fuel was converted into work, and this in spite of the circumstance that such a master mind as that of Smeaton had been directed to perfecting the new method of utilizing the potential energy of fuel, and of applying it to engines of large power, and on an extensive industrial scale.

The bent of Watt's mind was characterized by a love for abstract science, and it was, no doubt, for that reason that he abandoned his father's business and took up the profession of a philosophical instrument maker, in the pursuit of which he naturally came in contact with the meagre knowledge of physical science of the period, and with men eminent in the world of learning and of research.

The lucky chance which presented itself of having to put in order a working model of a Newcomen engine, illustrates in an interesting manner how, in pursuance of his business, he quickly executed the necessary repairs and alterations, and afterwards, at greater leisure, attacked the problem which the failure of the model presented, from the theoretical side, but soon found that the then state of knowledge did not afford the means of explaining the failure, and compelled him to set about the determination of such elementary data as the specific volume of steam, the latent heat of evaporation, and the law of tension of steam under varying temperatures. In the astonishingly short period of two years, and with the rudest and cheapest apparatus, he had furnished himself with the abstract knowledge required for explaining in a definite manner the action of the steam-engine, and he had no difficulty, as soon as his theoretical ground was sure, in determining what mechanical arrangements were necessary to realize the conditions imposed by science. From investigations, apparently of an abstract or non-practical character, sprung at once the separate condenser, the closed cylinder and the equilibrium working of a single-acting engine, the steam jacket, the air-pump, the theory of expansive working, the function of the momentum of the moving parts, and the exact calculations based on first principles by means of which the proportions of engines could be fixed, and the quantities of steam, water, and of fuel calculated. Watt, of course, was a born mechanic, as well as a seeker after physical knowledge. The workshop in his private house near Birmingham, happily preserved to this day as he left it, shows that his mind was ever bent on mechanical contrivances which his own hands were skilful enough to carry out; his valve-gear, the stuffing box, the parallel motion, the governor, are all instances of that happy blending of mechanical skill, and of scientific research, which must ever mark the qualifications of a great mechanical engineer.

A contrast to Watt's achievements is the singular history of the development of iron and steel bridge building, which necessarily followed the introduction of railways. Watt felt the want of first

principles by which to shape his actions, and set about discovering them; but the principles which underlie the determination of stresses in braced structures, such as roofs and frameworks of various kinds, as well as those in solid bars subjected to the action of transverse forces, have long been known; and early in this century Navier made them the subjects of lectures at the École des Ponts et Chaussées, yet engineers in this country seem to have been but dimly aware of them, or, at any rate, to have made little use of the knowledge which was at their disposal. It is difficult, from the published histories of such enterprises as the Conway and Britannia bridges, to arrive at any conclusion as to the extent of knowledge, or rather ignorance, which existed among engineers before these works were commenced. It is probable that some of a specially scientific turn of mind, but who were not in conspicuous practice, had a deeper insight into principles than the men whose great natural genius and knowledge of affairs placed them in prominent positions in the great railway enterprises of the day. It is sufficiently evident, however, from the long series of purely tentative experiments by which the proportions of the Conway and Britannia bridges were determined, as well as from the singular vagaries to be noticed in the smaller bridges of that day, that only the haziest ideas of the disposition of stresses, and of the functions of the component members of girders existed. This naturally led to timidity as to the capacity of girders to carry, unaided, the loads it was sought to impose, and induced a preference for masonry or for suspension bridges, with respect to which much wider experience was at command.

In the experimental investigations of the time, the function of the web or vertical member of a girder was completely ignored, for it was looked upon merely as the means of keeping the top and bottom flanges in their relative positions, while the essential difference in effect of a uniformly distributed load, or of a rolling load, as compared with a load concentrated at the centre, on the vertical member of a girder, and even on the flanges, appears to have been overlooked till made evident by the results of experiment; and the grave doubts which arose as to whether the girders of the two great tubular bridges could be made self-supporting are apparent to this day in the preparations made in the piers and abutments for the introduction of auxiliary chains. Yet the principle that a force cannot change its direction unless combined with another force acting in a direction inclined to it, was perfectly well known, and should have led to the discovery that it is only by diagonal stresses in the vertical members that the load resting on a beam can be

transmitted to the abutments, or be made to produce effects at right-angles to its own direction in the flanges; and that the stresses due to loads concentrated at the centre were very different to those arising, both in the vertical web and in the flanges, from the action due to a load distributed in a given manner along the top or the bottom flanges, and that a rolling load would produce effects peculiar to itself.

The girder with diagonally braced webs, or the lattice girder, as it is commonly called, appears to have had its origin in Ireland; at any rate it was in that country that it received its earliest and chief development; but at first, as illustrated by the bridge which used to carry the Dublin and Drogheda Railway over the Grand Canal in Dublin, it was a mere attempt to substitute for plate webs an arrangement of flat bars sloping in opposite directions, placed very close together, and having the oppositely inclined bars connected at their intersections by countersunk rivets.

This was naturally a very wasteful arrangement; but soon, in the hands of C. H. Wild, Barton, Bow, and Stoney, the true principles began to assert themselves, and Mr. Barton's Cusher River bridge, of 70 feet span, on the Great Northern of Ireland Railway, was probably the first example of a lattice girder in which the cross-sections of the members of the webs as well as those of the flanges were correctly proportioned to the stresses imposed by a rolling load. This comparatively small bridge was followed by the Boyne viaduct at Drogheda, which must ever rank as a signal illustration of the successful application of abstract principles to a great work by men who were capable, not only of appreciating them, but of following their guidance in a practical manner. The only experiments made during the preparation of the designs were those instituted to ascertain the power of resistance of the proposed braced diagonals to a compressive stress.

The wrought-iron portion of the viaduct consists of three spans, the main girders of which are continuous; and the points of contrary flexure in the middle, and larger span, were determined by direct calculation, the correctness of which was demonstrated in the actual structure by setting free the plates of the flanges at the points indicated,—in one girder at the top only, but in the other both at the top and bottom, and by observing the opening and closing of the plates so disunited when the land ends of the girders forming the side spans were raised or lowered.

Mr. C. H. Wild appears to have been the first to demonstrate correctly the distribution of stresses under any disposition of load

in the Warren girder, a form of beam in which the web is composed of a single system of diagonal bracing inclined at an angle of about 60°. In the museum of Trinity College, Dublin,[1] there has existed since, I believe 1854, a model of a Warren girder, 12 feet 6 inches long and 12 inches deep, in which the tension members both of the flanges and diagonal bracing are so arranged and articulated that any one section can be taken out and a spring balance inserted, by means of which it can be demonstrated that the stresses calculated for any disposition of load do actually arise.

Since 1848 the supremacy of theory over rule of thumb has gradually but surely asserted itself, though, at times, the want of common sense and experience in the application of abstract principles, as well, perhaps, as ill-judged efforts to produce cheap structures, has led to disasters quite as serious as those which arose from want of theoretical knowledge; and in this respect the competent and successful engineer will still show himself as the man who in his work is careful to make theory and practice walk side by side, the one ever aiding and guiding the other, neither asserting undue supremacy. This course, in its highest development, we may I think assert is that adopted by our leading engineers, with the result that this country may claim the honour of such a structure as the Forth Bridge, for the design and construction of which no tentative experiments were needed, though the form and mode of construction were very special, if not absolutely new; and the dimensions, both in span and height, so gigantic that the authors of the design could have derived but little aid from previous experience.

The history of scientific research teems with instances of discoveries which at first seemed to have had no practical value, but which nevertheless have ultimately proved to be of the utmost importance to the engineer. Notwithstanding such experience, and even in these days, there are so-called practical men who are utterly intolerant of either time or money being devoted to investigations which seem incapable of bearing immediate fruit. Many examples might be cited, for instance: the changes of temperature which occur in many chemical reactions were merely noted, at first, as interesting accompaniments to such reactions; but, by degrees, it was perceived that the amount of heat evolved or absorbed in each chemical change was a constant and definite quantity, which was capable of exact measurement, and in process

[1] This model was sent over and exhibited at the lecture.

of time the thermal values which characterised a vast number of chemical changes were determined, and are now considered of cardinal importance in many industrial operations, and constitute the science of thermo-chemistry.

At the same time the total heat of evaporation of water and of other substances was ascertained with great precision, so that it became possible to judge of the efficiency of a boiler, for instance, when the rate of fuel combustion and that at which the water was heated or evaporated were known, by calculating the proportion which the heat imparted to the water bore to that produced by the combustion of any fuel of which the chemical composition had been ascertained, and from which the heat capable of being developed could be calculated by general rules, and thus researches in the chemical and physical laboratories have had the ultimate effect of placing the theory of the steam-engine on a firm basis.

One practical consequence of the exact knowledge which every competent engineer now possesses on this subject, or can easily obtain, is that inventors have ceased to squander their time and their means in seeking for impossible high boiler duty, and the public is no more entreated to try contrivances which are to save at least 50 per cent. of the fuel they use, because inventors know that the testing of boilers is now usually carried out by experienced and educated men, who, by very simple and inexpensive trials obtain the data by means of which they can calculate with certainty how much scope for improvement actually exists.

Still more remarkable perhaps is the application of thermo-chemistry to the complicated reactions in the blast and regenerative furnaces, and the valuable conclusions arrived at in consequence by such thorough and patient investigators as Sir Isaac Lowthian Bell, Sir William Siemens, Charles Cochrane, and others who have succeeded in equating the heat-units resulting from the oxidation of fuel to the ultimate thermal results of the decomposition of the ore and fluxes, showing thereby the limits of economy which the ironmaster may hope to reach, and the proportions of the furnaces in which his expectations may be realized.

No less valuable have been the fruits yielded by the discovery of the great law of the Conservation of Energy, and by the recognition of the fact that, though energy cannot be destroyed, it may be made to assume various forms, and may be rendered either dormant or active. The sun's rays, æons of ages ago, during the dense vegetation which characterised the period of the coal measures, expended their energy in tearing asunder the carbon and oxygen of the carbonic acid so sparsely distributed through the

atmosphere, and in storing the carbon, thus endowed with potential energy, in the deposits whence we now derive our coal supplies. By suitable arrangements this dormant energy is quickened into that quality of motion which we recognise as heat, and which, setting into sympathetic vibrations the material of the furnace-plates and smoke-flues of boilers, operates on the surrounding water, the molecules of which, under this influence, assume the more extended movements of the highly elastic substance which we know as steam. The products of combustion, on the one hand, are restored to the atmosphere, their remaining store of heat is slowly dissipated, while the carbonic-acid gas produced in combustion is again ready to present itself, in the green leaves of plants, to the decomposing action of the sun, and by that means the carbon and the oxygen become once more sources of heat. The steam produced, on the other hand, communicates its molecular motion to exernal bodies in various heating operations, in the visible motion and force of the steam-engine or into the slower dissipation through space or over the earth, whereby it is again condensed to water and returned to its normal condition, while the energy, for the exhibition of which, Carnot has taught us, steam was the mere agent, becomes transformed into masses of water lifted, into air compressed, into electrical currents generated, into mechanical work done, or into the heat developed by friction; but the general tendency is towards dissipation under the form of heat into space, the waste being made good by the stores of heat poured on to our planetary system by the huge and mysterious body which is its centre. Whence this enormous and apparently unfailing supply of heat is derived has been, and still is, the subject of most interesting controversy, the upshot of which seems to be that the heat developed by the shrinkage of our luminary and by the fall on to its surface of meteoric matter is sufficient to keep up the supply at any rate for many thousand years.

But modern investigators, and, most of all, engineers, are not content with vague statements such as I have just made; they hold with the motto of the ancient Society of Civil Engineers, "Omnia in numero pondere et mensura," and they are therefore greatly indebted to Rumford, Carnot, Davy, Mayer and Joule, who not only showed that heat was a "mode of motion," but determined by tedious and delicate experiments its mechanical equivalent.

And what is now the result?

When examining heat-engines or other applications of heat in the arts, the engineer collects the apparently aimless work of half a century, and of many minds, and finds himself able to construct

a balance sheet in the manner first adopted, I believe, by Sir Frederick Bramwell,[1] by which he can show on the Dr. side, to a fraction, the quantity of heat he has received, and on the Cr. page, with astonishing precision, the manner in which that heat has been expended. This method of treatment is not only lucid, but it is self-checking, and it points out exactly how much heat has been uselessly dissipated, and consequently in what direction improvements may be made, and it indicated, further, the limits within which it is alone possible to make advances in economy.

These general principles apply even to the conversion of heat into the work done in the bore of a gun. The enormous pressures which require to be developed in order to impress high velocity on the projectile in the necessarily limited length of the barrel, the shortness of the time of action, and its violence, render it extremely difficult to obtain accurate and trustworthy records of pressures along the chase of a gun by direct methods; but by invoking the aid of the chemist and of the physicist in first ascertaining the properties of the explosive, that is to say, the specific volume of the gases, the quantity of heat evolved during combustion, and the specific heat of its products at high temperatures, it becomes possible to calculate curves of mean pressure which will account for the energy imparted to the projectile and to the expelled gases, although the question of abnormal local pressures, due apparently to the mode of ignition of the charge and the rate at which explosion is propagated through it, will not be revealed. This process is made the easier, in the case of smokeless explosives, because the products of combustion are wholly gaseous and retain that condition till expelled from the bore.

One of the loftiest of abstract conceptions relating to the structure of the universe, the product of many acute minds of this century, is the imagining of a substance of infinite tenuity but of immense elasticity, which permeates all space and every substance. It cannot be seen, or felt, or weighed, its composition is unknown, it cannot be pumped out of a closed vessel, it does not appear to offer any resistance to the motion of planetary bodies, and its existence is only made manifest by its property of transmitting chemical rays, light, radiant heat, electricity, and probably some more recondite forms of energy, at enormous velocity from the remotest regions of the universe and by means of vibrations the nature of which, the astounding frequency and minute pitch, have been determined by mathematicians. It is pardonable in human

[1] Minutes of Proceedings Inst. C.E., vol. lii. p. 155.

beings to disbelieve in the existence of the luminiferous ether, even though the profoundest thinkers and most successful workers of the present day may have all the conviction of Lord Kelvin, who has declared that "it is the only substance that we are confident of in dynamics, the one thing we are sure of is the reality and substantiality of the luminiferous ether!"

But what has the Engineer to do with such speculations, and what does it matter to him how light and heat are transmitted from the sun or from the stars, or by what mechanism heat, magnetism and electricity are diffused over the earth? This question is being answered already in our daily practice, and is destined, no doubt, to receive fuller and more convincing response as time rolls on. I will give one or two instances. The study of the spectrum produced by the passage of light through triangular prisms has revealed the fact that the ordinary rays of white light are of a complex nature, that only a portion of them are discernible directly by the sense of sight or by that of feeling, while the ultra-violet rays can only be seen in their action on Uranium glass, or in the chemical decomposition they produce in certain substances. This knowledge has been of immense use to the photographer, and has, in such hands as those of Captain Abney, assumed a highly practical value. But, further, the spectrum viewed by modern instruments is found not to be continuous, it is crossed by dark, by light, and by coloured bands, which the patient researches of Fraunhofer, Kirchhoff, Huggins, Norman Lockyer, and others, have shown by their position, thickness or colour to characterise certain glowing substances, and by comparison with the spectra produced by heated terrestrial solids and gases, it has been proved that many of the elements in the sun and in the stars are identical with those with which we are familiar on this earth, and this knowledge has served in a striking manner to confirm the correctness of the nebular theory as to the origin of our planetary system, advocated by La Place in his immortal work on the mechanics of the heavens.

Not only have a large number of terrestrial elements been discovered in the sun, but the spectroscope has revealed, to a considerable extent, the order in which they are arranged on the sun's surface, and this leads to the conclusion that at one time a similar order prevailed on the earth, and therefore throws some light on the deep geology of our planet.

One of the practical outcomes of these discoveries has been the theory of Mendeleeff on the origin of petroleum, a theory of the utmost importance to the human race, and to our country in

particular, in view of the inevitable exhaustion of our coal-supplies, for it asserts that petroleum is the product of the action of water on the carbides of metals at high temperatures at no very great relative depths in the crust of the earth, that this production is continually in progress, and that deposits thus actually forming may be reached in many places by sufficiently deep borings. It is somewhat humiliating, when thus drawing attention to the recent rapid advance of science, and to the manner in which the engineer has adapted the discoveries of the abstract investigator to the use and convenience of man, to be obliged to confess how utterly insignificant are human operations with reference to the size of our planet. The deepest mine is a mere scratch on its surface, so that though the theory of Mendeleeff may be true, the question arises whether there be any hope that the wealth inferred to exist may ever be realized, whether the powers of the engineer will ever be so exalted as to enable him to reach those stores of combustibles which that theory supposes must exist in many localities, especially in those where the surface has been much shaken by primeval convulsions, and where the deposits may, therefore, be expected to lie at relatively short distances below the surface? In view of recent progress in mechanical skill, it certainly would be rash to say that borings of immensely greater depth than any that we are as yet acquainted with will never be made, for if accumulated evidence as to the correctness of Mendeleeff's views together with the ever-increasing cost of fuel, shall hold out hopes of success, enterprizing men will be found ready to embark their means in undertakings, the risks of which would not seem to be more formidable than those which surrounded the laying of the first Atlantic telegraph cable, and the rewards of success in which would be incomparably greater.

But the spectroscope is doing yeoman's service nearer home, and producing practical results of the greatest importance. It is one of the most delicate instruments for chemical analysis. By its indications in 1860 Bunsen discovered the metals Rubidium and Cœsium in the waters of the Dürkheim mineral spring, though the quantities were so small that only from 3 to 4 grains of the chlorides of the metals existed in a ton of water. With the composition of metals used in the arts the engineer is especially concerned, and it is now well known that extremely small additions of foreign substances produce momentous effects. The influence of small quantities of arsenic, of lead or of bismuth on copper; of carbon, of phosphorus, of sulphur, of manganese, and of silicon and other substances on iron are extremely practical questions;

and every engineer who has examined the properties of materials seriously, acknowledges that the influence of a foreign substance on the mechanical properties of a metal bears no relation to the minuteness of its quantity.

The researches of Roberts-Austen, of Osmond, Le Chatelier, and others, are slowly, but it is hoped surely, establishing laws by which the relative atomic volumes of ingredients will become a guide to the nature of their mutual interaction, and it seems probable that spectrum observations which are of such value in gauging the purity of the materials dealt with, will come in aid and in support of the indications given by automatically traced curves of rates of cooling, which have given such a deep meaning to the phenomenon of recalescence, a property of iron and steel which for many years remained a mere laboratory curiosity.

But the undulatory theory of the transmission of radiant energy has an important bearing on the molecular constitution of matter. All substances, according to modern views, are built up of atoms or of molecules endowed with more or less motion of various kinds, and this implies that there is room for such motion, and explains what used formerly to be classed as one of the properties of matter, namely, porosity. Clerk Maxwell, Clausius, Lord Kelvin and many others, have endeavoured to penetrate into the structure and properties of the molecules and of the ultimate atoms, and the subject is of so recondite a nature as to be worthy of such minds; but without attempting to discuss the theories which have been advanced, it is clear that heat plays an important part in the relations between the atoms and molecules, and that that heat is communicated unceasingly, though, perhaps, often indirectly in the form of radiant energy emanating primarily from the sun. As long as temperature remains constant, all other things being the same, no change occurs, but with changes of temperature, changes in the energy of molecular motion take place, and when these pass certain limits, critical states are reached in which additions of heat cease to cause a change in temperature, or even a change of volume, but are expended in very large relative quantities in either changing the nature of molecular motion or in greatly extending it. So we have the commonly accepted three states of matter, solid, liquid and aeriform; but it seems to me that there are other states also, such as the critical condition depending upon temperature and pressure, in which the substance is neither liquid nor gaseous, solid nor liquid, and which has been investigated for many substances, and is exceedingly pronounced in carbonic acid. But many bodies, including metals and their alloys, may exist in

more than one form; sulphur, for example, assumes two allotropic states, but at ordinary temperatures and in a comparatively short time the one condition passes into the other. Mr. Addenbrook has recently prepared an alloy of aluminium and nickel, which when freshly made possesses considerable tenacity, but which, after a few hours, crumbles into powder. The researches of Osmond seem to show that pure iron also can exist in two states, one very hard—the other soft; and it is more than probable that these states merge into each other under certain conditions of heating or cooling, or under the influence of foreign substances. There can be no doubt that steel also, in course of time, undergoes molecular change at ordinary temperatures, and possibly under the influence of strains produced by internal stresses due to unequal rates of cooling. It is a common opinion, based on experience, that tool steel should not be used as freshly made, but should be kept some months; and the same precaution applies to dies used in coining and similar operations, and to armour-piercing shot, both of which, having been hardened by necessarily unequal and rapid cooling, either accommodate themselves to the stresses engendered by slow changes in the motion of the molecules or fail spontaneously even after months of repose. Glass undergoes similar changes, and generally materials which have been severely strained either by the external application of force, or by heating, will only gradually recover their normal condition. This has been beautifully demonstrated by Professor Hughes, with the aid of his induction balance, on specimens of the narrow steel ribbon used in the manufacture of Longridge wire-guns. A number of specimens recently submitted to him showed a remarkable uniformity of structure, but when heated to only 100° and examined immediately on cooling to the normal temperature, a distinct change was observable, yet after a few hours' rest the material returned to its normal state. If such changes are measurable in ribbon $\frac{1}{4}$ in. $\times$ $\frac{1}{16}$ in. in cross section, what may not be the molecular conflict in large masses? These may be produced by alternations of stresses as well as by changes of temperature, and point to the necessity of assisting the molecules and atoms to adjust themselves or to return to a normal condition by raising the temperature of the substance to about the point indicated by *b* on Chernoff's scale, below which no change in the nature of crystallization takes place, no matter how slowly the mass is allowed to cool. This principle is recognized in many ways in the arts. In drawing wire or in solid drawn metal-work, such as tubes and cartridge-cases, periodical annealing must be resorted

to, moreover experience has shown that crane-chains, for example, should be annealed from time to time if they are to be used with safety; and Mr. Webb has adopted, with the best results, the plan of treating in a similar manner the moving parts of his locomotives after they have run a certain number of miles.

I feel convinced that the frequent disasters with screw-propeller shafts, especially after they have been some time in use, arise from the failure to recognize the practical bearing of the tendency to molecular change under the influence of strain and temperature. A propeller shaft is subject to constant variations of stress due to the action of the cranks of the engine, to similar variations caused by the inertia of the screw, and again to a totally different set of stresses which may often be alternately tensile and compressive, due to the wear of the journals and to the working of the hull. The remedy, I feel convinced, lies in the periodical annealing of the material which must, of necessity, be so hardly used.

I think that it is now generally acknowledged that the luminiferous ether is also the medium by which electrical energy is transmitted by some kind of vibratory motion; hence the ease with which heat or mechanical work is transformed directly into electric currents in the thermopile, or in the frictional electrical machine, and the reasonableness of the great generalization that we are living on a huge magnet—the poles of which are not far from coinciding with the poles of the earth. To what purpose are the endless observations on the deviation and dip of the magnetic needle which are so assiduously carried on by every civilized nation, and what interest have engineers in the painful labours of those daring explorers who set up their Observatories amidst the endless ice and the darkness of the Polar regions?

Let such a questioner, if there be one, study the construction of the mariners' compass, and especially in the improved form introduced by Lord Kelvin; let him compare the blind groping after correction for the local attraction of the ship with the beautiful and simple theory which has rendered that correction not only easy but readily adapted to changes in the ship's position in the world; he will find that there is not a more striking instance of the profoundest abstract knowledge blended with the power to turn it to practical use, than in this and in so many other labours of the distinguished man whom I have named more than once, and whom this Institution is proud to number among its honorary members.

I will not dwell upon the wonderful results of which we are

to-day reaping the benefit, and which have arisen from the application of the most profound scientific knowledge to the problems which arise in the generation, storage and application of electricity, to the transmission of power, to telegraphy, and to lighting, but I would draw your attention to a startling consequence of the undulatory theory in the power which exists of exercising influence, by what is termed induction, at great distances. Animated by the conviction that electric energy was transmitted in the same manner and by means of the same all-pervading medium as radiant energy, and that the distance to which its effects would reach should be unlimited, though the appreciation might be a question of the delicacy of instruments, Mr. Preece has succeeded in sending messages by Morse signals across the Bristol Channel between Lavernock and Flatholme, a distance of over 3 miles. The electro-magnetic disturbances were excited by primary alternating currents, having a frequency sufficient to generate a low musical note in a telephone, in a copper-wire 1,237 yards long, erected on poles along the top of the cliff on the mainland. The radiant electro-magnetic energy was transformed into currents again in a secondary circuit 610 yards long, laid along the island parallel to the first and at a distance of 3·1 miles; the messages were read off on the island through the instrumentality of the induced currents, and the experimenter was gratified to find that the results obtained on the secondary-wire were in complete accordance with the expectation which theory led him to entertain.

Any one who has meditated deeply on the nature of the luminiferous ether and on its universal presence has probably felt that it must also be concerned in the action of the human brain. The mechanisms of the "five gateways of sense" have been worked out by anatomists and physicists, but their researches are incompetent to declare how the impressions sent along the nerves at last reveal themselves as images or perceptions in the mind. Lord Kelvin has discoursed on this matter; he has suggested the existence of a magnetic sense, and has shown that the mind may be influenced independently of the recognized organs of perception. There are undoubtedly occult phenomena which can only be accounted for by the supposition that one mind can interact upon another, even as Mr. Preece's parallel wires acted on each other.

Setting aside the immense amount of calculated delusion and imperfect observations which has characterized animal magnetism, clairvoyance, &c., though probably not more than astrology, necromancy, transmutation of metals, and other delusions, hampered the early advance of physical and chemical science, there still

remains a substantial amount of authentic fact on which argument may be founded. Professor Oliver Lodge drew attention to the matter in his Presidential Address to section A at the meeting of the British Association in Cardiff in 1891, and in the opinion of that acute investigator the subject seems to deserve the attention of scientific societies. The influence of mind upon mind is undoubted, whether between great leaders of men and their followers or between individuals. How comes it that such men as Law, Napoleon, Wellington, Father Mathew, Parnell, Gladstone, Booth, Lesseps, and many others, for good or ill, have been able to exert such marvellous influence over immense masses of men? and how have individuals acquired the power of influencing the conduct of others or of discerning their hidden intentions or actions as shown in well-authenticated cases of what is known as mesmerism and thought-reading? Numerous, too, are the cases of presentiment, or knowledge of events which have taken place at a distance, and about which the person informed has not even been thinking; and there is, again, the whole region of dreams, with reference to which we are in complete ignorance.

I do not think that it is at all a wild idea to imagine that the process of thought or of will going on in one mind may be communicated, like light or heat, to another either by contact and conduction, as in thought-reading, or by awakening induced thought, as when one person is able to establish a powerful influence over another.

The poet frequently penetrates at random deeper and earlier into the mysteries of nature than does the sober man of science. Lord Byron, in two remarkable stanzas in "Childe Harold," alludes to the "electric chain with which we are darkly bound," and, with all the grace and simplicity which characterizes his verse, points out how trifling and accidental circumstances appear to have the power of awakening thoughts and images which we had long supposed buried in oblivion!

It cannot be said that engineers are not interested in this question.

Is it not the occult influence which great engineers exert upon their clients that renders the carrying out of important and hazardous works possible? Where were the enterprizes which have immortalized the names of Brunel, of the Stephensons, of Hawkshaw, of Fowler, of Baker, of Lesseps, or of the daring promoters of the transatlantic telegraph cables, had not these men had the power of communicating unbounded confidence to those who supplied means in such abundance and at such risk!

It surely is desirable to ascertain by what mechanism this singular influence is exerted, and if the key to the mystery be found to lie in the luminiferous ether, it seems to me that large prospects of advantage to the human race present themselves, and we shall have fathomed another mystery of nature, which, on the face of it, does not seem to present greater difficulties than many which have been triumphantly overcome.

It is less than fifty years, for example, since the nature of epidemics and the mode of their propagation seemed to be beyond the reach of human comprehension, and when Pasteur commenced his classic investigations into the causes of fermentation and of contagious disease, no one, I presume, thought that such an abstruse study as bacteriology could ever be of the least interest to engineers, nor would they have thought that the controversy relating to spontaneous generation, which raged so fiercely only a few years ago, could have influenced the science to which they were devoted.

But the triumphant demonstrations of Pasteur, of Lister, of Burdon Saunderson, of Tyndall, and of many other workers at home and abroad have shown that there is no such thing as spontaneous generation; that zymotic diseases, those scourges of animal and vegetable life, are caused by living organisms whose modes of propagation and of travel are being eagerly studied and are day by day being better understood; they have shown that we are no longer fighting at random against an unknown and covert enemy, but are face to face with a subtle foe whose tactics we are rapidly learning to understand. We have discovered that his best allies are to be found in the carelessness of his victims as to cleanliness, to drainage, and water-supply, and that his most formidable enemy is the engineer, who, being guided by the abstract investigations of the biologist and the chemist, can select with certainty the most fitting source of potable water, and can get rid of the sewage of centres of population, not only without inflicting injury on the surrounding community, but very often actually benefiting them by removing existing sources of pollution and by increasing the productiveness of the soil.

The gradual but steady decrease in the death rate and the increase in the duration of human life, the greatly reduced virulence of many epidemics, the total extinction of some, and the means of protecting from their assaults, may be cited as instances of the successful practical application of abstract principles which has not only conferred great benefits on man, but in the end opened up fresh fields of activity for the engineer.

But not alone in sanitary matters has bacteriology produced

profitable results; it may truly be said that the great industries of brewing, of wine and vinegar-making, and many other manufactures, have been placed on a sound footing by the knowledge we now possess of the occult action of ferments and of bacteria: and even in agriculture the true nature of the operations which take place in soil, by which the nitrogenous food of plants is rendered capable of assimilation, is one of the triumphs of the research of these our days. Schloesing, Müntz, Pasteur, Munro, Percy Frankland and others, have shown that one of the most important of plant-foods in the soil is nitric acid, and that this substance is elaborated from ammonia by the action of minute living organisms. The singular fact has been demonstrated that the work is performed by a system of division of labour, one kind of bacterium converting the ammonia into nitrous acid and declining to do any more, when another species takes up the work and produces nitric acid, which presents the nitrogen in a form which can be assimilated by the plant. "Not only," to use the words of Dr. P. Frankland, "is this process of nitrification going on in the fertile soils, but enormous accumulations of the products of the activity of these minute organisms in the shape of nitrate of soda are found in the rainless districts of Chili and Peru, from whence the Chili saltpetre, as it is called, is exported in vast quantities, more especially to fertilize the overtaxed soils of Europe!" But more than that, long and patient research has established the fact that, in certain of the leguminous plants, the same microscopic agency acting in the roots endows them with the power of assimilating the nitrogen of the atmosphere, and by that means makes them the instruments for actually enriching the soil instead of exhausting it.

I have already alluded to the circumstance that the engineer cannot be satisfied with vague statements or with mere abstract opinions. The very nature of his calling implies action; he has to construct, his works must be stable, his machinery must act, his estimates of cost and of the consequences of his operations must come true, and hence he has to make a close alliance with that most fascinating and fruitful of the sciences—mathematics. It is not given to many to possess the peculiar aptitude which leads up to the highest investigation, but neither has the engineer often need of anything deeper than almost elementary knowledge, especially if he gets into the habit of working out the problems that come before him by the graphic methods which are now so assiduously cultivated, and if he will realize that slovenliness in the matter of calculations commonly leads to disastrous

results. Though his attainments may not be high, and though disuse may have made it difficult to wield the power which knowledge, early acquired, once gave him, yet he can always appreciate and put his faith in the great minds which delight in subjecting the theories of physicists to the rigid test of mathematical analysis, and thereby stamping them with the seal of irrefragable fact.

One great quality he must possess, especially in these days when numerous science colleges have rendered high mathematical training of easy access—and that is common sense. There is a tendency among the young and inexperienced to put blind faith in formulas, forgetting that most of them are based upon premises which are not accurately reproduced in practice, and which, in any case, are frequently unable to take into account collateral disturbances, which only observation and experience can foresee, and common sense provide against.

I have endeavoured to show how the history of abstract science, by which I intend to designate the history of researches entered into for the sole purpose of acquiring knowledge of the operations of Nature and of her laws, without any thought of reward, or expectation of pecuniary advantage, has had its reflex in the records of the engineering profession, and how the most recondite investigations, apparently unlikely to have any direct influence on our practice, have, in course of time, become of cardinal importance. I have also ventured to point out how, in these days, the engineer must banish from his mind the idea that anything can be too small or too trifling to deserve his attention. "Nothing is too small for the great man," is, I am told, written over the cottage once occupied by Peter the Great at Saardam. The truth embodied in that legend should ever dwell in our minds; for success, I am persuaded, lies largely in close attention to details.

You may perhaps think that I have endowed abstract science with undue importance, and that I have claimed too wide a domain for the engineer. If this be so, I would turn to the old and faithful Servant of this Institution, in whose honour it has been a labour of love to prepare this discourse, and ask him for his verdict.

You can anticipate his answer! Who does not know how jealous he is of the honour and prestige of our Institution? Who is not aware that he will not concede that any branch of physical science is beyond its province? Nor will he yield to any of the younger societies more than the position of tributary powers. He is glad, as we well know, to recognize, as our children, institutions

dealing with special branches of the profession; he is glad to foster them in every way, and rejoices to see them meeting under the eyes of the Fathers of the profession, whose portraits adorn these walls; but I am confident that he will declare that you cannot touch anything in Natural Science which will not, sooner or later, prove of advantage to the members of this Institution, and which the engineer will not, in time, turn to the moral as well as to the material advantage of the human race.

Mr. HARRISON HAYTER, President, said when he announced that the first "James Forrest" Lecture would be delivered, and that the lecturer would be Dr. Anderson, he stated in effect, if not in words, that it would be difficult to find anyone better qualified to undertake the duty, and from the cordial way in which the announcement was received, there appeared to be a general concensus of opinion in this respect. It had been said that it was unwise to prophesy before the event; but there were exceptions to every rule, and that this was one of them was proved by what they had heard that evening. A first lecture of the nature of the one they had been listening to demanded a lecturer of the highest rank; and in asking the Council to invite Dr. Anderson to deliver it, Mr. Forrest had shown characteristic discernment. The lecturer had treated a difficult subject with marked ability; and, if the lecture could be taken as a type of those to follow, it would augur well for the success of the "James Forrest" Lectureship. On behalf of the members, and on his own behalf, he congratulated Dr. Anderson on this excellent lecture; and he was quite sure they would all join in congratulating Mr. Forrest upon the happy inauguration of the lectureship associated with his name. The members had by their acclamation practically accorded a vote of thanks to the lecturer; but it was his duty formally to propose that "a cordial vote of thanks be tendered to Dr. Anderson for his lecture, and that he be requested to allow it to be printed, with a view to a copy being sent to every member of the Institution." He could only express a wish that a way might be found so that the lecture might be extensively circulated. The remarks Dr. Anderson had made as to Trade Unionism and other socialistic evils ought to be sent to every Member of Parliament, to County Councillors, to School Boards, and to other responsible bodies, so that the mischief done to all classes of society, especially to the working man, might be seen, and the necessity of teaching the truths of Political Economy become apparent to those in authority.

Mr. Giles, Vice-President, said he had much pleasure in seconding the resolution, not only on account of the skill with which Dr. Anderson had dealt with a very difficult subject, but because he had embraced so many branches of science in his lecture as almost to take away one's breath. He had given them also a very good lecture upon political economy, and he only hoped that the gentlemen to whom he referred would have the benefit of reading the lecture, and taking advantage of it in their future career. Fifty years ago English engineers taught nearly the whole world engineering. Since that time, according to Dr. Anderson, foreign engineers had gone ahead of them in science. That might be so; but he maintained, notwithstanding their scientific acquirements, they still wanted a practical knowledge of the work of Englishmen. He had been a great deal among foreign engineers, and his experience went to show that the perfection and finish of English work far exceeded anything he had seen abroad. He hoped this would still continue. It was true that foreign engineers might be more scientific than Englishmen, but he did not think that there were many foreigners whose names would exceed in brilliancy many of those to whom Dr. Anderson had alluded in his lecture. He was quite sure, if the members all applied themselves to the study of the different sciences referred to by Dr. Anderson, they would derive great advantage from having listened to his lecture. He was old enough to remember that fifty or sixty years ago they had not the advantage of the scientific education given at the present time. He had been greatly struck with one remark of the lecturer: "Here again I am in accord with Past-Presidents who in their addresses have dwelt on the importance of practical training. I hold that an engineer's education should begin earlier, and should embrace those branches of knowledge which in our great public schools are still in a great measure ignored." He quite agreed with that sentiment, and well remembered that when he was almost a boy he used to wonder what was the use of so much Latin and Greek. He would only add his thanks to Dr. Anderson for his admirable lecture, and his hope that it might be published for the benefit of the members.

The motion was unanimously adopted.

Dr. Anderson said he thanked the President and Mr. Giles for having so kindly proposed a vote of thanks to him, and the members for having so warmly received it. It had been a great grief to him, as he was sure it would be to the members, that Mr. Forrest's state of health had prevented him from being one of